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Formulation of Plantain Flour-Based Pasta: Process Optimization and Sensory Evaluation

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ABSTRACT

In order to promote locally made agriproducts, diversify the use of plantain-based flours (Musa AAB) in Cameroon and improve on the dietary situation of celiac patients in the world by formulating accessible gluten-free foods, flour from a plantain variety (Big ebanga) was used for the production of pasta. Physicochemical characterization of plantain flour and durum wheat flour was done. The Response Surface Methodology (RSM) was used to study the effect of the quantity of 3 factors (water, egg white and xanthan gum) on the cooking quality of pasta (swelling index and cooking loss). The optimal conditions were determined for each response. Therefore, the two formulations retained and the classic one was coded for sensory evaluation using the 9-point hedonic scale. The physicochemical characterization of flours revealed a significant difference ($p<0.05$) in the evaluated parameters except for lipid content. Regarding optimization, only the quantity of xanthan gum influenced the evaluated responses. Sensory evaluation results revealed three categories of panelists following their preferences, and enabled to bring out two conclusions: 1. plantain-based flours are fit for the manufacture of pasta, and 2. it is relevant to improve on some organoleptic qualities of plantain flour-based pasta in the framework of further studies.

Keywords
Optimization, Pasta, Plantain flour, Sensory evaluation.

Introduction

Agriculture is one of the driving forces of the economies of most African countries in general, and Cameroon in particular. Its role is to boost local markets and protect people against rising food prices in international markets [1]. However, propelling agricultural development without thinking of the efficient and effective means of processing and/or preserving the derived products seems to be a mere utopia. Plantains scientifically known as *Musa paradisiaca* are grown in more than 120 countries on five continents and over 10 million hectares [2,3]. Cameroon's production is about 4,314,910 tons [4]. This crop occupies a prominent place in agriculture of most countries in West and Central Africa, where it is a staple food and a major component of food security [5]. They are used in the production of recipes and other food products like crisps, flour, flour-based products including pancakes, donuts, bread and jams [5-9]. According to the country and the dietary habits of consumers, unripe banana flour has been studied as a functional ingredient, mainly as a source of unavailable carbohydrates, such as resistant starch, which is its most expressive component. Several studies on the unripe banana flour fermentation have shown its high ferment ability and production of short-chain fatty acids (SCFA) [10]. Consumption of wheat-based products such as pasta is prominent in diets even in non-wheat countries. The latter are becoming more and more dependent on wheat-producing nations, especially during economic crises where wheat is very expensive to import. In response to this situation, there is an increasing development of wheat flour substitution technologies using local food resources [11]. For the same purpose, FAO launched in 1964 a major program for the valorization of local cereals, roots and tuber crops. Since then, most FAO research has shown that it is possible to partially replace wheat with local cereals and tubers such as sorghum, millet, maize and cassava in bread making, and other new derived products [12]. In Africa, research efforts are being made for the use of locally available flours, in order to reduce expensive imports of wheat, to increase the use of local foods and to reduce post-harvest losses in plantain estimated at nearly 25% [13,14]. Therefore, this study aims at formulating plantain flour-based pasta, in order to diversify the use of plantain flour.

Material and Methods

Description of the study area

The study was conducted at the Post-harvest Technology Laboratory of the African Research Center on Bananas and Plantains (CARBAP), in Njombé, Njombé-Penja District, Moungo Division, in the Littoral Region of Cameroon – in collaboration with the Research unit of Biochemistry, Medicinal plants, Food Sciences and Nutrition of the University of Dschang in Cameroon.

Material

Biological Material

The plant material consisted of durum wheat semolina obtained from LA PASTA S.A. (pasta producing industry in Cameroon) and plantain flour derived from *Big ebanga* cv. This plantain cultivar was grown in a mini-collection of bananas, set up as part of the C2D/PAR-PLANTAIN project. It was chosen because of its availability, its productivity and its high consumption in the Littoral region of Cameroon. It has been widely disseminated since the 2000s by CARBAP in West and Central Africa (WCA). In addition, its production cycle is relatively short (10 months) and its dry matter content is high compared to other local varieties, thus making it possible to obtain a good quantity of flour.

Ingredients

The main ingredients were: plantain flour, wheat flour, water, and formulation additives (egg's white, salt, extra refined palm oil, and xanthan gum). Salt, extra refined palm oil and eggs were purchased from the market, and xanthan gum was ordered from manufactory industry of chemical substances named Sigma-Aldrich in USA. It is important to mention that refined palm oil was used to facilitate the extrusion process of pasta.

Technical materials

The following laboratory equipment was used: - an electric scale (model ADAM basic type NBL-4602i with a capacity of 4600 g and reading accuracy of 10^{-2}) - a kneader (a Kitchen Aid brand propeller mixer, Model 5KSM 150 made in USA) - a pasta extruder machine (LACRANGE® pasta CREATIV brand which has different parts: a part reserved for kneading and a part reserved for extrusion) – a muffle furnace (model VECSTAR) – an oven (Memmert brand, model 600) - cookware made of knives, pots, pails, skimmer and colander - a gas cooker- an artisanal gas oven - an ordinary artisanal mill.

Methods

Production of plantain flour

Undamaged unripe green fruits of *Big ebanga* from the mini collection of the C2D/PAR-PLANTAIN project was chosen and washed. They were then peeled, and pulps cut into cubes of about 1 cm^3, resulting in "*cossettes*" which underwent a physical treatment using boiling water for 3 to 5 minutes. Drying was carried out for 36 to 48 hours in a gas oven whose temperature was controlled between 45°C and 50°C. The dried "*cossettes*" were ground using an ordinary artisanal mill. Figure 1 shows the steps of flour production from plantain pulps.

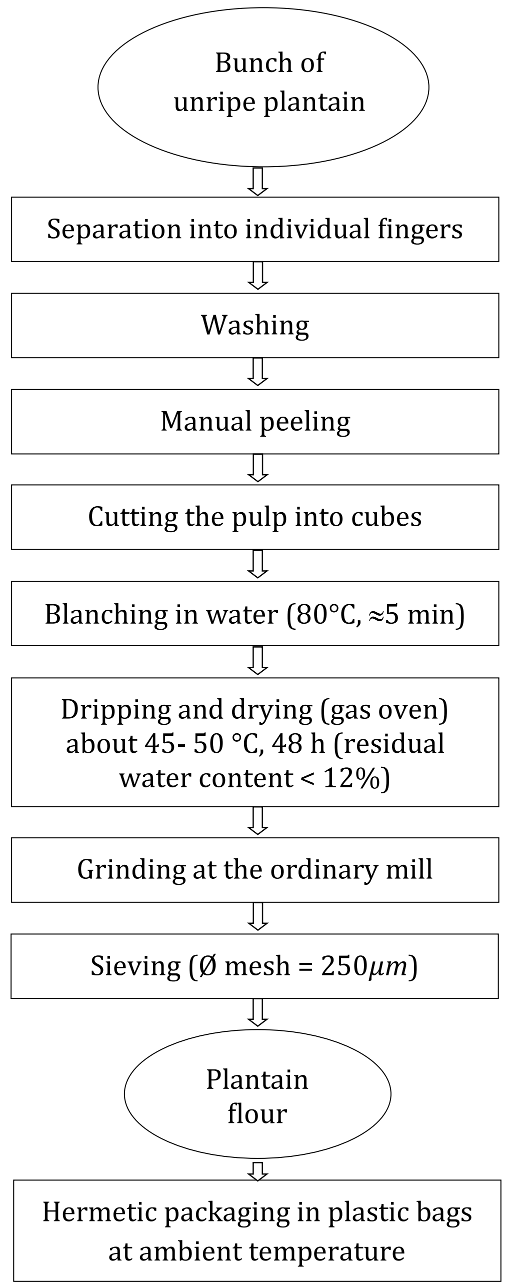


Figure 1: Plantain flour flow chart (Adapted from [5]).

Chemical characterization of flours

Moisture Content

The moisture content (MC) was determined using a modified AOAC method [15] based on the measurement of the mass loss of the samples after drying at 105°C until complete removal of free water and volatile compounds. The vacuum cup was first cleaned, dried and weighed (M0). A mass of 5 g of sample was weighed (M1) and then placed in a Memmert oven, model 600 at 105°C for about 24 h. The cup was taken out of the oven and then cooled in a desiccator before being weighed (M2) again. The moisture contents were calculated using the formula below:

$$MC = \frac{M1 - M2}{M1 - M0} \times 100$$

Total Ash Content

The total ash content of the flours was determined according to the AOAC method [15]. It consisted in mineralizing 5 g of flour. The vacuum mineralization crucible was first cleaned, dried and weighed (M0). The crucible containing the wet product (5 g) was again weighed (M1) and placed in an oven at 105°C for about 24 h. After drying, the crucible was removed from the oven and cooled in a desiccator before being weighed (M2). Once weighed, the crucibles were introduced into the Vecstar furnace at 550°C, incinerated until it gets a white color for about 48 hours, cooled in the desiccator and reweighed (M3). The ash content was expressed according to this formula:

$$\text{Ash content } (\%) = \frac{M3 - M0}{M1 - M0} \times 100$$

Evaluation of the Total Soluble Solids (TSS) Content

The refractive index (RI) or TSS content of the flour was determined as follows: 15 g of flour were diluted in 45 ml of distilled water. The whole was homogenized using a Fisher brand® magnetic stirrer for about 5 min. After resting the mixture, a drop was placed on the prism of a handheld refractometer (REF 113, Brix, 0 - 32 ATC). The recorded value was multiplied by three as the sample of flour extract was diluted in a triple volume of distilled water [16]. The soluble dry extract ratio in "°Brix" was calculated using the following formula:

TSS (°Brix) = 3 RI– 0.8

Determination of pH and total titratable acidity (TTA)

The electrode of a pH-meter (HANNA instrument) was immersed in a beaker containing 20 ml of sample at ambient temperature (≈ 25°C). The result was read on the pH-meter screen. 5 ml of each flour sample were placed in a 20 ml beaker, 5 ml of distilled water were added to the beaker, and then 3 drops of phenolphthalein were added. The whole was titrated with 0.1 N sodium hydroxide solutions (NaOH) until a persistent pink color was obtained for about 10 seconds. The TTA was determined using the formula.

TTA (meq/100g) = 1200 x V_{NaOH}

Determination of lipid content: Soxhlet method [15]

The filter paper bags for analysis were pre-dried in an oven at 105°C for 2 hours and cooled in a desiccator for 1 hour and then weighed (P). 5 g of sample (m_e) were then added thereto and the sealed assembly was weighed (P1). After 7 hours of extraction, the assemblies were again dried in an oven at 105°C for 1 hour 30 minutes, cooled in a desiccator for 30 minutes and weighed (P2). The lipid contents were then calculated by the following formula:

$$\text{Lipids } (\%) = \frac{P1 - P2}{P1 - P} X100$$

Determination of total protein by the method of Kjeldahl [15]

The protein content determination of the samples was carried out using micro Kjeldahl method as described by AOAC (1990), which consists of wet digestion, distillation and titration. The protein content was determined by adding 3g of sample into a boiling tube with 25ml concentrated sulphuric acid and one catalyst tablet (5g K_2SO_4, 0.15g $CuSO_4$, 0.15g TiO_2). They were heated at low temperature for digestion to take place. The digest was diluted with 100 ml of distilled water, 10 ml of 40% NaOH and 5 ml of $Na_2S_2O_3$ anti-bumping agent were added, after which the component was diluted into 10 ml of Boric acid. The protein content was calculated using this formula:

$$\%\textbf{Protein} = \frac{(\textbf{ATV} - \textbf{TB}) \times 0.1 \textbf{ NHCl} \times 0.014 \times 6.25}{\textbf{Weight of sample}} \times 100$$

Where ATV = Actual Title Value; TB = Title of Blank

Determination of total carbohydrate content (G)

The total carbohydrate content was determined by the difference between 100 and total sum of the percentage of fat, moisture, ash, and protein content. G = 100 - (MC+AC+P+L)

Where: MC = Moisture Content (% DM); AC= Ash Content (% DM); P =total protein content (% DM); L = lipid content (% DM).

Optimization of process' conditions for the production of pasta

Factors and experimental domain

Response Surface Methodology (RSM) has been used in this study to determine the optimum condition required to obtain good quality pasta. The effects of three independent variables [water quantity (X_1), egg white quantity (X_2) and xanthan-gum quantity (X_3)] on two response variables (cooking loss and water absorption) were evaluated. The central composite design (CCD) 2^3 + star was used. In this type of design, each of the independent variables is taken at two levels meaning that each variable has a low and high numeric value. A coded numeric value of "-1" and "+1" is assigned to represent the variable's low and high values respectively. In this case where we had 3 factors, we had two trials for the central point, 2 trials for the factor, 2 trials for the first factor at the axial point, the third factor at the axial point; making a total of 16 trials [17]. The use of Central Composite Design (CCD) helps to: (a) study the effect of parameters, (b) create models between variables (c) determine the effect of these variables and (d) optimize the levels of ingredients [18]. The experimental domain (Table 1) used to obtain the experimental matrix (Table 2) was obtained from preliminary test and a second polynomial model generated as shown below:

Y=β0+β1X1+β2X2+β3X3+β11X211+β22X222+β33X233
β12X1X3+β13X1X3+β23X2X3

Command variable	Coding levels				
	-α (-1.73)	-1	0	+1	+ α (+1.73)
	Real values				
Quantity of water (X_1)	50.00	54.30	60.00	65.70	70.00
Quantity of white egg (X_2)	40.00	43.01	47.00	50.99	54.00
Quantity of xanthan gum (X_3)	0.00	0.40	0.93	1.46	1.87

Table 1: Coded levels and real values of factors.

Trial	Experimental matrix			Real values		
	X_1	X_2	X_3	X_1 (ml)	X_2 (g)	X_3 (g)
1	0	0	0	60.00	47.00	0.93
2	0	0	0	60.00	47.00	0.93
3	1	1	1	65.70	50.99	1.46
4	1	1	-1	65.70	50.99	0.40
5	1	-1	1	65.70	43.01	1.46
6	1	-1	-1	65.70	43.01	0.40
7	-1	1	1	54.30	50.99	1.46
8	-1	1	-1	54.30	50.99	0.40
9	-1	-1	1	54.30	43.01	1.46
10	-1	-1	-1	54.30	43.01	0.40
11	α	0	0	70.00	47.00	0.93
12	-α	0	0	50.00	47.00	0.93
13	0	α	0	60.00	54.00	0.93
14	0	-α	0	60.00	40.00	0.93
15	0	0	α	60.00	47.00	1.87
16	0	0	-α	60.00	47.00	0.00

Table 2: Experimentation matrix for optimization.

Where Y is the measured response - β_1, β_2 and β_3 are coefficients determined from the results of experiments, - X_1, X_2 and X_3 are linear effect factors, - β_{12}, β_{13}, β_{23} are coefficients determined respectively from the results of interaction effect of X_1X_2; X_1X_3 and X_2X_3 factors - β_{11}, β_{22} and β_{33} are coefficients determined respectively from the results of the quadratic effect of X^2_1, X^2_2 and X^2_3 factors.

The criterion used to accept the proposed model is given by the high determination coefficient (R^2) value, assumed as a value exceeding 75%, leading to the conclusion that the model explains a high percentage of total variability [19]. The coefficient of significance has been analyzed with reference to the factor contributing to the adjustment of the model to a 5% level of significance.

Production process

Pasta made from plantain flour consists of a mixture of plantain flour to which water, egg white, xanthan gum, extra refined palm oil and salt were added. The assembly was subjected to mechanical transformations such as mixing, kneading, extrusion, drying and packaging for subsequent analyses (Figure 2).

Appreciation of pasta quality

The properties that define the quality of pasta were determined through their behavior during and after cooking (swelling and loss of materials), their nutritional value, their hygienic state and their sensory quality [20].

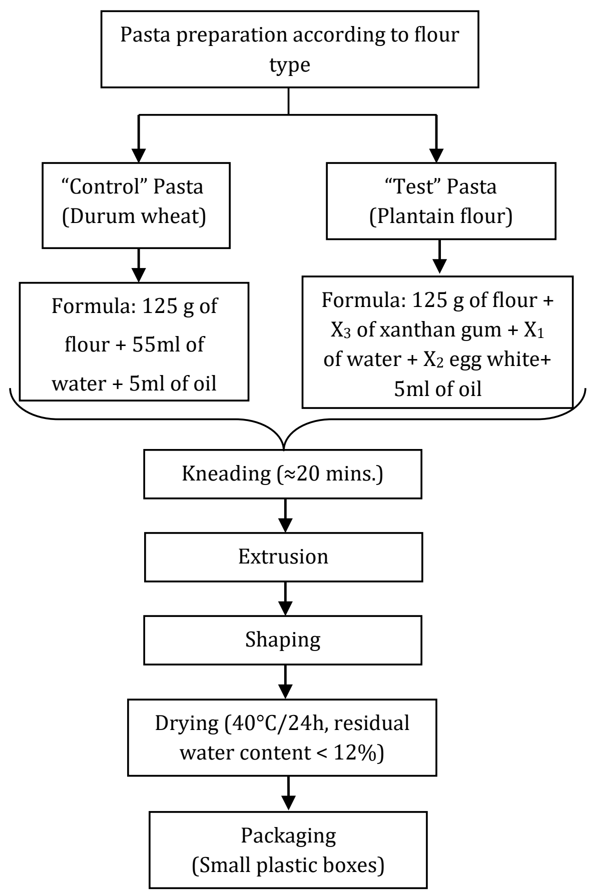


Figure 2: Pasta manufacture flow chart.

Cooking quality

The culinary quality of the pasta made in our study was appreciated by the determination of the Optimum Cooking Time (OCT), the swelling of the pasta and their losses during cooking (degree of disintegration). The culinary properties were evaluated on gluten-free pasta from the experimental design and durum wheat pasta (Figure 3). The various culinary parameters were determined three times for each formulation of plantain-based pasta.

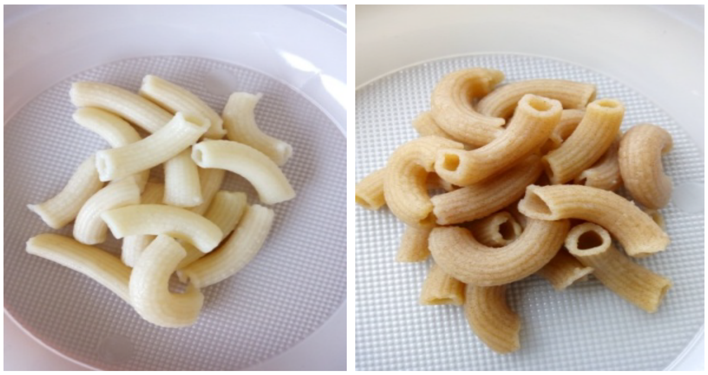


Figure 3: Cooked pasta made from durum wheat semolina (left) and plantain flour (right).

Optimum cooking time (OCT)

The optimal cooking time is considered as the time required to fully gelatinizing the starch. A sample of pasta was immersed in a water previously heated to boiling (pasta: water ratio = 1:30) without the addition of salt and without stopping the boiling of water. Every 30s, a strand of pasta is removed and immediately crushed between two glass plates. Optimal cooking time corresponds to the time required for the disappearance of the central white part [21].

Water absorption capacity (WAC) or Swelling index (SI)

Swelling is defined as the weight gain of pasta during cooking and indicates the amount of water absorbed (starch gelatinization and protein coagulation). This is therefore an index of the water absorption capacity of the pasta [21]. A sample of 10g of plantain flour pasta was cooked in 300ml of water previously heated to boiling at the optimal time of cooking. The cooked pasta was drained and weighed. The swelling index is calculated using the following equation:

$$\mathbf{SI\ (\%)} = \frac{\mathbf{WCP - WUP}}{\mathbf{WUP}} \times \mathbf{100}$$

Where WCP = Weight of Cooked Pasta and WPU =Weight of Uncooked Pasta

Cooking Losses

Disintegration represents a fundamental criterion of the culinary quality of cooked pasta and defines the behavior of pasta after cooking [22]. The dry matter (DM) of the uncooked pasta is first determined by drying 5 g of pasta in an oven at 105 ° C for 6 hours and weighing until a constant weight is obtained. A 5g sample of pasta made from plantain flour is cooked to OCT and then rinsed with water and weighed. The dry matter of the cooked plantain flour-based pasta was determined after drying the pasta at 105 ° C for 10 hours [24]. Cooking loss is calculated as follow:

$$\text{CL (\%)} = \frac{\text{DMCP} - \text{DMUP}}{\text{DMUP}} \times 100$$

Where DMCP = Dry Matter of Cooked Pasta and DMUP = Dry Matter of Uncooked Past.

Sensory evaluation of noodles

The development of this test involved 92 naive subjects. The formulated products (Figure 3) were coded and presented to consumers for them to choose the product they liked most. Before analysis, both pastas were cooked at their respective cooking times. The control form (100% semolina wheat) and two other forms from the "trials" (100% of plantain flour) were put in the dishes of each taster randomly for their appreciation.

Hedonic test

For reasons of space and convenience of the tasters, the sensory tests were carried out in the Laboratories of CARBAP and University of Dschang. They were implemented according to the AFNOR Standard XP V 09-500 [23]. The consumer panel consisted of 92 persons of different educational level, different occupation, both sexes and variable ages. During the tests, consumers were invited to taste each pasta shape one after the other while rinsing their mouths with water between each product. They then gave their opinion on the color, the taste, the texture, the visual aspect and the overall appreciation of each product tasted on a 9-points hedonic scale: 9 = extremely pleasant to 1 = extremely unpleasant [24].

Statistical analyses

The results obtained within the framework of this research are the average of three repetitions. They were analyzed using – Stat graphics software version 5.0 for the experimental analysis of optimization data - R software version 3.4.1 was used for the analysis of physicochemical parameters of flours and - XLSTAT 2017 for the hedonic analysis of the cooked pasta. The comparison of the means was done by the DUNCAN test to classify the treatments which were significantly different at $p<0.05$ (5% threshold).

Parameters	Plantain flour	Wheat flour
Moisture (%)	12.25 ± 0.15^a	13.37 ± 0.34^b
Proteins (%)	3.68 ± 0.25^a	14.00 ± 0.44^b
Lipids (%)	1.31 ± 0.024^a	1.46 ± 0.006^a
Carbohydrates (%)	81.50 ± 0.34^a	70.37 ± 0.45^b
Ash (%)	1.24 ± 0.22^a	0.78 ± 0.19^b
Total soluble solids contents (°Brix)	6.00 ± 0.34^a	5.00 ± 0.17^b
pH	5.43 ± 0.03^a	5.840 ± 0.06^b
Total titratable acidity (meq/100g)	1529 ± 107^a	1341 ± 70^b

Table 3: Chemical characteristics of raw materials (plantain and durum wheat flour).

The different letters in the same column indicate a significant difference ($p<0.05$)

Results and Discussion

Chemical characteristics of raw materials

Table 3 shows the average contents and the chemical properties of the flours used in this study. The plantain flour used in pasta formulations was less moist and contained very little protein compared to semolina, which was rich in total protein, and was used for the production of "control" pasta. However, plantain flour was significantly more acidic, richer in total carbohydrates and total ash, and had a higher pH and soluble solids content than durum wheat semolina. It is worth mentioning that lipid contents did not vary significantly in both flours.

Water and protein contents

The water content recorded for plantain flour is 12.25%, indicating that it is less moist than semolina wheat. However, this value is higher than 8% and 10% during the characterization of plantain flour for noodles and pancakes [8,25]. The difference in this water content could be due to the variability of the harvesting season, the production location and the storage conditions as well as the plantain variety. Analysis of the protein content of plantain flour revealed that it contains less protein (3.68 % DM) compared to *Cavendish* banana flour whose protein content obtained during the nutritional assessment of banana flour was 4.14% [26]. The protein contents of our plantain flour are in line with 3.40% DM and 3.9% DM obtained respectively during the nutritional assessment of noodles produced from plantain flour and the use of bananas for the manufacture of food products [25,27].

Ash, lipid and carbohydrate contents

The ash content of *Big ebanga* flour is higher than that obtained from *Cavendish* banana flour (1.084%) and lower than that obtained on flour produced from the *Orishele* plantain variety [26,28]. These differences could either be linked to the agricultural production conditions (soil types, climate, planting season, nature of the fertilizers) or to the storage conditions (relative humidity of the storage room, type of packaging, etc.). The fat content of durum wheat semolina used in the manufacture of the "control" pasta is 1.460% DM. This value is lower than 1.96% DM reported by Yesli [29]. The lipid content of *Big ebanga* flour (1.31% DM) is closer to data obtained on other plantain varieties (1.35% - 1.8% DM) [20,22]. The carbohydrate content of the plantain flour is 81.50% DM. Similar values were obtained on some plantain cultivars [27]. However, the data obtained on *Big ebanga* was lower than that found on a plantain variety analyzed in Nigeria (89.5% DM) [25].

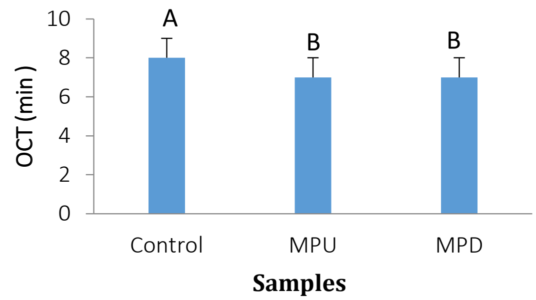
Total soluble solids content, pH and total titratable acidity

The refractive index (°Brix) of plantain flour derived from cv. *Big ebanga* is greater than that obtained on flour from cv. *Orishele* [30]. However, the result is similar to the value of 6.2 °Brix obtained during pancake formulation [8]. In addition, wheat semolina has a lower refractometric index than plantain flour. This could mean that plantain flour is very energetic than wheat semolina. The pH value of plantain flour is lower compared to 6.39 obtained on flour from the same plantain variety (*Big ebanga*) [8]. The average titratable total acidity of plantain and wheat flours is respectively 1 529meq/100g and 1 341meq/100g. It increases as the pH decreases. The titratable acidity of *Big ebanga* flour is lower than that found on the same cultivar in 2017 (1741.2 meq/100g) [8]. The differences observed in both parameters could be attributed to the variability of the harvest season as the same cultivar was in the same locality for both studies.

Optimizing the influence of the amount of xanthan gum, egg white and water on the degree of disintegration

Determination of the cooking time of manufactured and commercial pasta

The determination of the optimum cooking time is a necessary step to evaluate cooking losses (degree of disintegration). This time corresponds to the optimal cooking time which results in the complete gelatinization of all the starch contained in the grain [31]. Figure 4 shows the optimal cooking time of control pasta made from durum wheat semolina (8 min) and that of pasta formulations based on plantain flour (7 min).



The different letters indicate a significant difference (p <0.05) between the cooking time

Figure 4: Optimum cooking time (min) of different samples.

Analysis of variance of cooking loss and swelling index

Table 4 shows the analysis of variance of the responses. The factors that significantly influence the cooking loss is the linear effect of the quantity of gum, the quadratic effect of egg white and the volume of water as their p-values was less than 0.05. The swelling index on the other side was significantly influenced by the quadratic effect of the volume of water and xanthan gum. The coefficient of determination R^2 of the water absorption and cooking losses are respectively 84.47% and 85.35%, showing that there is equivalence between the experimental values and the predicted theoretical values [18].

	Cooking loss		Swelling index	
source	sum of squares	p-value	sum of squares	p-value
linear				
X_1:QW	0.744241	0.5384	0.0333208	0.9754
X_2:QEW	1.03864	0.4702	38.8974	0.3138
X_3:QXG	23.4333	0.0106*	9.87806	0.5997
quadratic				
X_1X_1	14.7043	0.0274*	60.2667	0.0188*
X_2X_2	16.9638	0.0207*	9.72932	0.6023
X_3X_3	0.00000980224	0.9982	449.852	0.0096*
interaction				
X_1X_2	0.14553	0.7827	327.808	0.2203
X_1X_3	5.87045	0.1167	48.0102	0.2678
X_2X_3	0.214185	0.7383	135.055	0.0865
constant	-308.884		409.056	
R^2	85.3526%		84.474%	

Table 4: Analysis of variance of the optimization of cooking loss (CL) and swelling index (SI).

**Significant effect for p<0.05;*
QW: quantity of water;
QEW: quantity of egg white;
QXG: quantity of xanthan gum

Proposal of the model

The regression equations of cooking loss (CL) and swelling index (SI) expressed as a function of the amount of water (X1), egg white (X2) and xanthan gum (X3) is presented below:

$$CL = -308.884 + 4.59725X_1 + 7.63683X_2 + 18.1853X_3 - 0.0387768X^2_1 + 0.0059304X_1X_2 - 0.283557X_1X_3 - 0.084998X^2_2 - 0.077375X_2X_3 - 0.00366192X^2_3$$

$$SI = 409.056 - 3.04541X_1 - 9.4528X_2 + 184.51X_3 - 0.0785034X^2_1 + 0.28146X_1X_2 - 0.810907X_1X_3 - 0.0643707X_2^2 - 1.94295X_2X_3 - 24.8074X^2_3$$

The negative sign in front of each linear or interaction coefficient indicates that the factor decreases the responses and vice versa.

Isoresponses curves for the amounts of xanthan gum, egg white and water on cooking loss and swelling index

Figure 5 shows the isoresponse curves of cooking loss (a) and swelling index (b). It also presents the effects of the different control variables on cooking loss and swelling index while delimiting the optimal zones. In general, the isoresponse curve indicates that the CL % varies between 8 and 15%. The selected areas of interest are areas with low levels of degree of disintegration (below 9%) in order to have a CL close to that of durum wheat pasta (5.6%) [32]. Thus, the factor levels for optimal formulation of low cooking loss are: QXG (1.4g - 1.87g), QEW (48g - 54g) and QW (64ml - 70ml). Furthermore, the SI varies between 165% and 170%. Areas of interest were selected on the basis of the highest swelling index (equal to 165%) close to that of durum wheat pasta (255%) [33]. Thus, the factor levels for a formulation with a high SI are: QXG (0.4g - 1.5g), QEW (40g - 54g) and QW (50ml - 70ml).

Cooking Loss or degree of disintegration

According to some authors, cooking loss would be the most important parameter to consider during the evaluation of the culinary quality of pasta [34,35]. Therefore, the minimum cooking losses obtained on the isoresponse curves, and the optimal range of cooking loss (CL <9%) xanthan gum [1,6 -1.87g], egg white [50.5-55g] and water [66.5-70 ml] were considered. In general, the isoresponse curve plotted (Figure 5) shows that the CL varies between 9% and 15%. These results overlap with data obtained on gluten-free pasta made from rice ranging between 4.2% and 15.9% [36]. However, these values are higher than that of durum wheat pasta (5.6%) [32]. Whatever the level of xanthan gum, the cooking loss of plantain flour-based pasta decreased with increasing levels of water and egg white.

The influence of xanthan gum on the degree of cooking loss as shown by the analysis of variance (Table 4) was predictable. Xanthan gum has been used by several researchers for the formulation of gluten-free pasta for the improvement of its firmness and a significant decrease in cooking losses [37]. The degree of disintegration decreases significantly when xanthan gum (1-2%) is added in the formulation of gluten-free pasta. This is due to the development of a system by the soluble fibers around the granules of starch, thus leading to an increase in the cohesion between starch and proteins in the structure of the pasta [38]. High concentrations of egg white significantly influence the degree of disintegration. Egg proteins (albumin) facilitate the formation of a network of tight proteins that coagulate under the effect of heat and trap the granules of starch during cooking, therefore, limiting the swelling and losses during cooking [39,40].

Water absorption capacity or swelling index

The iso-response curve (Figure 5) shows that swelling index (SI) varies between 135% and 170%. These results are in line with literature data obtained on gluten-free pasta with a swelling index at intervals of 77.3 to 141% [20,39,41] that appear to have a higher water absorption capacity, compared to durum wheat control pasta, 124.11% DM. No factor significantly influenced this response.

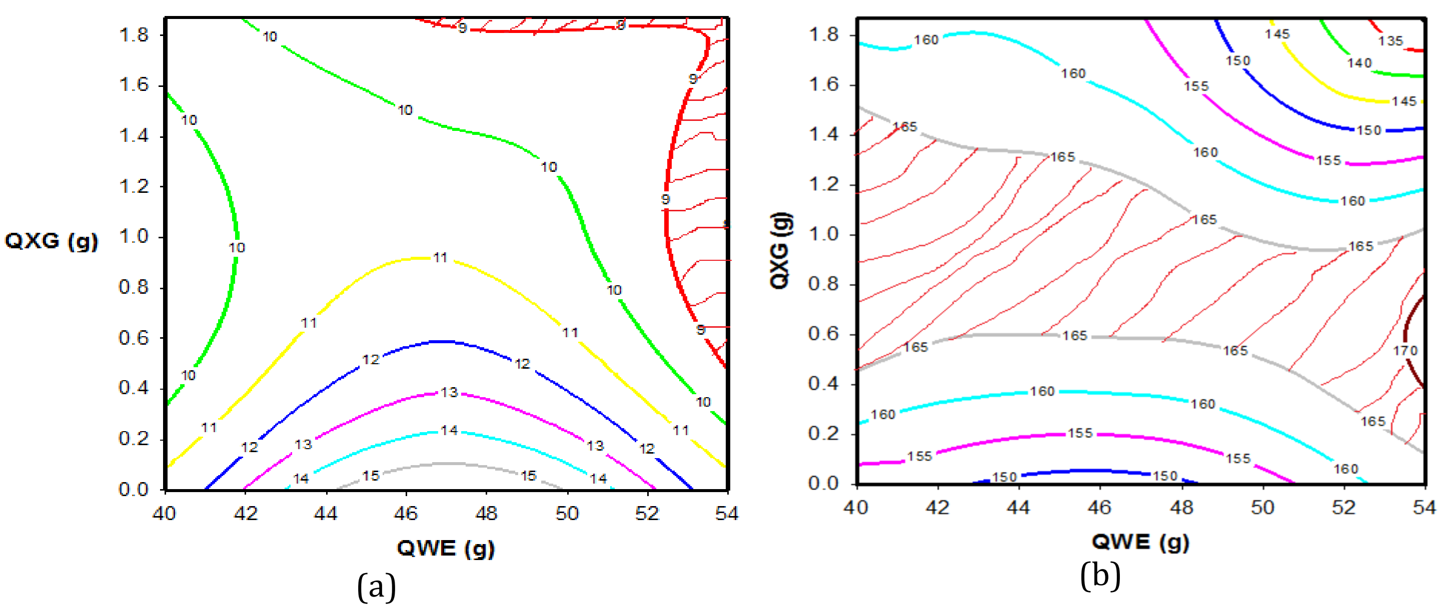


Figure 5: Isoresponse curves of degree of cooking loss CL% (a) and swelling index (b) of pasta according to the amount of xanthan gum and egg white content.

Several studies have shown the influence of xanthan gum and egg white on water absorption. On pasta with rice, the increase in xanthan gum resulted in a significant decrease in the swelling index [42], due to the leaching of amylose during gelatinization by formation of a gum-amylose complex. Opposite trends have been observed where gums improve the swelling of gluten-free pasta due to their ability to form a gel even in small quantities that provide a high consistency, even at room temperature [43]. This thereby justifies the influence of the quadratic effect of xanthan gum on the swelling of pasta made from plantain flour. In other words, the gums compete with the starch in the presence of water and are responsible for the increase in the swelling of pasta during cooking [44]. Regarding egg white, there is a close relationship between pasta swelling during cooking and the agglutination as well as the thickening properties of eggs in gluten-free pasta [45].

Validation tests for optimal conditions

To verify the results of the optimization, two formulations were chosen in the optimal zone. The culinary quality of the verification points was assessed by determining the cooking losses (CL %) and swelling index (SI %). Analysis of variance of the degree of disintegration and water absorption results showed that gluten-free pasta (made of plantain flour) had significantly higher material losses in the cooking water and high-water absorption than those in the control (Table 5). There is also a significant difference in the degree of disintegration and water absorption between gluten-free pasta regardless of egg white and xanthan gum.

Samples	Cooking loss	Swelling index
MBL (control)	4.14^a ± 0.41 %	124.11^a ± 2.30%
MPU	8.87^b ± 0.80 %	165.32^b ± 1.97 %
MPD	8.33^b ± 0.29 %.	171.44^b ± 1.56 %

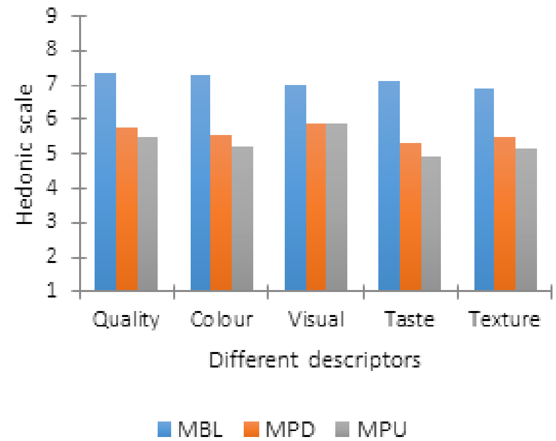
Table 5: Cooking loss and water absorption of different samples.
The different letters in the same column indicate a significant difference (p <0.05) between the different samples

Sensory evaluation

The purpose of this evaluation was to measure the assessment of three cooked pasta formulations: durum wheat semolina pasta “MBL” and two pasta made from plantain flour in the optimal range “MPU” and “MPD”. The consumers gave their appreciation on some organoleptic properties such as: the taste, the color, the texture, the visual aspect and the overall quality appreciation using the 9-points hedonic scale: from 9 (extremely pleasant) to 1 (extremely unpleasant). The composition of the different formulations use is shown in Table 6. Figure 6 shows the sensory scores of the panelists. The pleasant or unpleasant characters of the pasta formulated were measured through the hedonic test. The data were processed statistically and the analysis of variance (ANOVA) showed that there is no difference between the two formulations based on plantain flour. However, significant variability was observed between plantain flour products and the wheat flour control formulation. Mouth feel and taste are important attributes in assessing the sensory characteristics of pasta [46]. Firmness and elasticity are the main parameters measured in pasta texture assessment [47]. The MBL sample was significantly different from the MPU and MPD samples in terms of visual appreciation, texture, taste, color and overall rating. This could be explained by the difference in raw materials used for pasta production [40,25].

Pasta formulations	Water (ml)	Egg (g)	Xanthan gum (g)	Oil (ml)	Salt (g)
MBL (control)	55,0	-----	-----	5,0	1,0
MPU	66,5	50,5	1,60	5,0	1,0
MPD	70,0	54,0	1,65	5,0	1,0

Table 6: Composition of pasta used for hedonic analyzes.



The different letters show the significant differences (p <0.05) between descriptors of different samples

Figure 6: Sensory characteristic of the different pasta formulation.

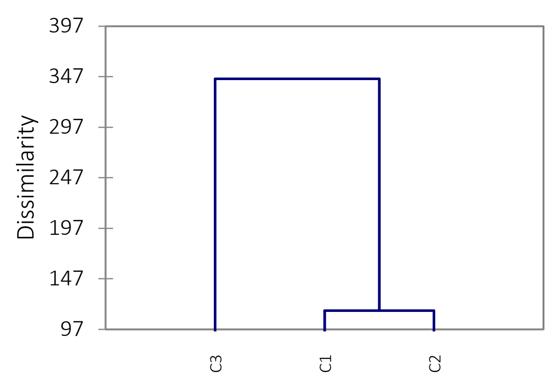


Figure 7: Different classes of consumers.

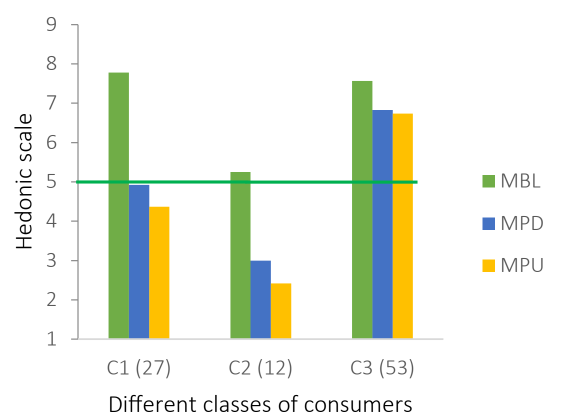


Figure 8: Different classes of consumers according to their preference.

Analysis of data from the hedonic evaluation enabled the construction of a dendrogram that highlighted three classes of consumers with different preferences, classes C1, C2, and C3 made respectively of 27, 12, and 53 consumers (Figure 7). Depending on their preferences, class C1 brings together consumers who like pasta made from wheat semolina; class C2 groups consumers who do not like pasta whether made from wheat semolina or from plantain flour and class C3 covers consumers who like as much wheat semolina pasta as plantain flour-based pasta (Figure 8). They represented about 60% of the participants to the survey. Durum wheat flour, unlike plantain flour contains gliadins and glutenins that form the gluten network whose behavior significantly affects the rheological properties of pasta, give pasta their extensibility, elasticity and plasticity. It can also be explained by the fact that the tasters are not used to consuming pasta of color other than white. As far as color is concerned, it is due to the brown color of plantain flour, which is rich in beta-carotenoids, the precursor pigments of vitamin A [27], compared to that of durum wheat. From a general point of view, plantain flour pastes have good sensory characteristics and are accepted by about 60% of the consumers because the values attributed to organoleptic characteristics are above the average.

Conclusion

This study shows that there is a significant difference in physicochemical parameters of wheat and plantain flours (proteins, carbohydrates, ash, humidity, total soluble sugar, pH and total titratable acidity) except for the lipid content which does not differ significantly. Concerning optimization, cooking losses are significantly influenced by xanthan gum. The egg white and the volume of water have very little influence on the degree of disintegration, but their quadratic level (high concentration) significantly influences the cooking losses. Regarding the swelling index, none of the three factors significantly influence this response, but at high concentrations they have a significant influence on this response. Pasta made from plantain flour from optimum areas is characterized by relatively shorter cooking times than those made with durum wheat semolina and the loss of material in the cooking water is significantly low. The sensory tests of three pasta formulations (two derived from plantain flour and one from durum wheat semolina), made it possible to retain a better formulation, coded as MPD and made of 70ml water + 54g egg white + 1.65 xanthan gum + 5ml oil and 1.0g salt. MPD was widely appreciated by consumers and displayed organoleptic properties close to the more preferred control formulation (MBL). This study indicates that plantain-based flours are fit for the manufacture of pasta. It would be remarkable to focus on other interesting plantain varieties (*Mbouroukou n°3* and *Batard*) and on "scale transfer problems" that may occur during industrial production of pasta made from plantain flours.

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